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A REVIEW TO ASSESS THE POSSIBILITY OF THERMAL AQUACULTURE OF CRUSTACEANS

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ABSTRACT

The literature was reviewed to assess the culturability of crayfish, freshwater prawn and lobster, and the feasibility of thermal aquaculture of these crustaceans in southern Ontario. The technical and economic viability of culturing the crayfish, *Procambarus clarkii*, and the prawn, *Macrobrachium rosenbergii*, has been proven in warmer climates. Culturing of *Procambarus clarkii* and *Macrobrachium rosenbergii* may be possible in southern Ontario if heat is added to culturing systems adapted for local conditions. Potential sources of heat are discharges from generating stations and electric heating. Culturing the lobster *Homarus americanus* has not as yet been demonstrated as feasible. On the basis of the potential marketability, culturability and technical viability of culture systems for *P. clarkii* and *M. rosenbergii*, development of these two species for thermal aquaculture was recommended.

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To Mr. F.J. Kee
Director of Research

A REVIEW TO ASSESS THE POSSIBILITY OF THERMAL AQUACULTURE OF CRUSTACEANS

J.K. Kwik

1.0 INTRODUCTION

The demand for prawns and lobsters is readily identified by the large number of food outlets that list these crustaceans on their menu. Although the demand for crayfish, which are also crustaceans, is not nearly as prominent, their palatability has been recently publicized by the news media.

At present most of the crustaceans consumed in Ontario are imported at a premium price. If technically viable commercial culture systems can be developed, it may be possible to culture these crustaceans in southern Ontario by enhancing and optimizing their survival, reproduction and growth through temperature control. Culturing these luxury products in Ontario would provide a source of fresh prawns, lobsters and crayfish year round which command a premium price. The development of technically and economically viable thermal aquaculture systems (culture sytems to which heat is added) would result in the use of electricity and possibly waste heat.

The objective of this review was to assess the culturability of crayfish, prawns and lobsters and to evaluate the potential of thermal aquaculture of these crustaceans in southern Ontario. The species reviewed were several local Ontario species, the southern United States crayfish, *Procambarus clarkii*, the west coast crayfish, *Pacifasticus leniusculus*, the freshwater prawn *Macrobrachium rosenbergii*, and the the lobster *Homarus americanus*. In this review commercial decapod culture techniques currently used were described and their yields presented. The temperature requirements for rearing the animals and the effects of temperature on their growth rate were also investigated. Suitable species for further development were identified and their market potential assessed.

2.0 CRAYFISH

Crayfish occur naturally in freshwater habitats on all continents except mainland Africa. In North America they are harvested in large numbers in Louisiana and California and in lower numbers in Wisconsin, Washington, and Oregon. Commercial culturing is practised mainly in southern Louisiana (Nolfi 1980).

Although the demand for crayfish in southern Ontario has been as bait for anglers rather than as human food, these crustaceans have long been considered a delicacy in Europe and are a major source of animal protein in New Guinea and Madagascar. They were consumed by Indians in parts of North America before the arrival of Europeans. At present in North America they are consumed mainly by persons of French and Scandinavian heritage (Nolfi 1980).

Major urban markets for crayfish presently exist only in New Orleans and Baton Rouge, but Nolfi (1980) believes that markets can be established in most major metropolitan areas. His impression is based on the results of a study concerned with developing a market for southwestern Louisiana crayfish in Houston (Carrol et al 1976, in Nolfi 1980). Similarly, Griffin (1975, in Nolfi 1980) conducted a study to characterize the target population and concluded that crayfish can be "marketed successfully in metropolitan markets as a 'gourmet' item sold at better restaurants and specialty food stores".

Jack Court of the Clearwater Bait Company in Oliphant, Ontario, has also discovered the popularity of crayfish as a gourmet food in Ontario. Based on consultations with Ontario and Federal government officials, Jack Court thinks that there is a good domestic demand for crayfish (Toronto Star, June 28, 1983). At present he delivers crayfish harvested from Georgian Bay, Lake Huron, to hotel restaurants and other eateries, in some instances replacing previously imported crayfish from Europe. The European crayfish were described by one chef as being "too costly".

2.1 Evaluation of North American Crayfish Species for Aquaculture

In this review the crayfish taxa considered for aquaculture purposes were the local Ontario species, *Orconectes virilis*, *O. propinquus*, *O. rusticus*, *O. obscurus*, *O. immunis*, *Cambarus bartoni*, and *C. robustus*, the west coast species, *Pacifasticus leniusculus* and the southern species *Procambarus clarkii*. Commercial aquaculture for human consumption is presently

limited to *P. clarkii* which is cultured extensively in parts of Louisiana.

For ease of culturing four characteristics were considered necessary. The species must be aquatic, must prefer temperatures at or above southern Ontario ambient temperatures, should be omnivorous, and should not require brackish conditions at any stage of their life cycles.

A decision matrix (Table I) was employed to evaluate the suitability of the crayfish for culturing. Only characteristics for which information on all species could be found in the literature were used. Four variables were ranked in terms of importance or desirability for culturing and are described in order of importance. For the marketing of crayfish for human consumption large animals are desirable. Therefore size (total length) was considered to be an important variable. The ratio of tail length to total body length did not vary much between species, but was considered to be of some importance since only the tail is consumed. Tail to total body length ratios were obtained by measuring photographs of the species under consideration. Species showing a preference for lakes and ponds rather than for rivers and streams in their natural distributions are preferred for culturing since lake and pond conditions are easier to simulate. Thus habitat preference was also considered an important variable. Frequent spawning was considered an asset for culturing because it indicates the possibility of frequent recruitment.

The four variables were ranked with the most important variable given the highest rank. The species were assigned scores ranging from 1 to 10 for each variable with higher scores given to the more favourable species. The scores assigned to each species were then multiplied by the rank of the variable. The products were then added up for each species. The higher the final score the more desirable the species should be for culturing for human consumption.

This decision matrix gives an indication of the species that may be the most suitable for culturing as a food item. However, other important variables such as growth rate, age at which sexual maturity is attained, egg production, and aggressiveness were not included because these data were not available for all species.

Procambarus clarkii obtained the highest score indicating that it is the most desirable species for culturing. This species obtained a high score mainly because of its relatively large

TABLE 1

DECISION MATRIX

EVALUATION OF NORTH AMERICAN CRAYFISH SPECIES FOR AQUACULTURE

Variable	Rank	*Orconectes virilis*	*Orconectes propinquus*	*Orconectes rusticus*	*Orconectes obscurus*	*Orconectes immunis*	*Cambarus bartoni*	*Cambarus robustus*	*Pacifastacus leniusculus*	*Procambarus clarkii*
Size	4	16	4	32	16	8	24	28	40	40
Tail length: Total length	3	15	15	25	15	25	15	12	12	15
Habitat	2	10	10	20	10	20	10	10	20	20
Spawning Frequency	1	10	5	5	5	5	10	10	5	10
Total Score		51	34	72	46	48	59	60	77	85

size. *Pacifastacus leniusculus* and *Orconectes rusticus* obtained the next two highest scores, again mainly because of size.

The literature was searched for any indication of differences in growth rates and maximum body length relative to latitude. Only limited data were obtained for *O. virilis* the most widely distributed of the crayfish found in Ontario. The maximum sizes recorded did not appear to be directly related to latitude although the smallest value was recorded for animals from a river in Alberta (Aiken 1968), the northern most location for which data were found. The records for the two largest values were obtained from Michigan (Hazlett et al 1974) with one of the localities identified as being in southeastern Michigan, probably the southern most district for which records were obtained.

P. leniusculus and *P. clarkii* are the species with the southern most distributions and are the two largest species of those studied. However information on their growth rates and maximum size relative to their distributions was not available.

Of the crayfish considered, *P. clarkii* appears to be the best suited for commercial aquaculture. Its large size would make it more marketable than the smaller species while its habitat preference and spawning frequency makes it a favourable culture species.

2.2 Culture Methods for Crayfish

The requirements for culturing crayfish are relatively simple. Culturing techniques for *Orconectes virilis* were described by Leonhard (1981) for mass culturing in tanks and are summarized here. Laboratory mass culturing requires holding tanks with a continuous flow of water and a reservoir with heating and cooling equipment. Polyvinylchloride piping (70-120 mm long, 50-70 mm diameter) cut in half lengthwise may be placed in the tanks for burrows. Fluorescent lighting equipped with a timer switch to maintain photoperiod is also required.

The tank loading density is 1 g crayfish per mL of water daily. The water level in the tanks is kept at 10 cm. The flow of water from the reservoir to the holding tanks should be established at 200 mL/min. The water should be dechlorinated and the calcium level adjusted to 40-70 mg/L. The fluorescent lights should provide approximately 50 $\mu E/m^2/s$ at the water surface. Light and temperature should simulate natural regimes.

From mid-October to mid-February, the animals should be kept in total darkness and should not be fed or disturbed approximating normal conditions under ice. During this period the water flow

is stopped and the tanks maintained as static systems providing 1 mL of water for each gram of crayfish for each day of confinement.

The tanks are stocked with 20 ovigerous females and 20 mating pairs from a spring or summer collection or from another established culture. The crayfish are fed extruded crayfish food to the equivalent of 1% of their total body weight. The ovigerous females should be examined frequently for hatchlings.

The hatchlings should be removed and placed separately into subdivided aquaria two-thirds full of dechlorinated water. The hatchlings should be fed the equivalent of 10% of their weight in extruded crayfish food every other day.

The culturing method described by Leonhard (1981) is suitable for mass culturing in a laboratory setting. The culturing requirements for commercial purposes are discussed below.

Crayfish may be cultured in various sized open ponds. A 20 ha pond is regarded by the Louisiana Wildlife and Fisheries Commission as the size which provides maximum profit per dollar invested (Gary 1974). A soil substrate apparently will result in higher survival rates than a solid bottom since it allows for burrowing during the quiescent period when crayfish retreat to a secluded place, usually a burrow, and mature females lay eggs (Huner 1976). Oxygen depletion is a major cause of crayfish culture pond failure (Avault et al 1974). Therefore the water source should have a dissolved oxygen level of at least 3 ppm or the water must be aerated as it is pumped in the pond. A filtering system is also recommended since it keeps potential predators such as fish out of the pond (Clark et al 1974).

Although crayfish are omnivorous and capable of subsisting on almost any type of food (Tarshis 1978), studies conducted by Clark et al (1974) on *Procambarus clarkii* indicated that optimal growth occurred for animals given pelleted and extruded food. Thus to enhance growth supplementary feeding with pelleted or extruded food is desirable.

For initial stocking of the pond Lacaze (1970, in Clark et al 1974) suggested supplying adults at a rate of 67.2 to 112.0 kg/ha to open ponds or 44.8 to 50.4 kg/ha to densely vegetated ponds. In Clark's study stocking rates of approximately 31,000 and 62,000 young crayfish/ha were used for a projected production of 500 to 1000 kg/ha, with an average weight per crayfish of 23 g and 70% survival at time of harvest.

Forney (1956) who reported on experimental cultures of *Orconectes immunis* in artifical ponds in New York recommended that pond area be limited to under 1/2 acre (0.2 ha) for ease of harvesting and management. His stocking requirements are 600 - 1000 mature crayfish per acre in the fall and 300 - 500 females with eggs per acre in the spring. He recommended fertilization of the ponds with commerical fertilizer (6-12-6 or 10-10-5) at a rate of 200 lb/acre (1.1 kg/ha) at three week intervals during spring and summer. As an alternative he suggested the addition of 20 to 30 bushels (2-3 m^3/ha) of manure per acre at three week intervals. Fertilization of the ponds will stimulate growth of rooted and microscopic plants. According to Forney (1956) crayfish can survive on microscopic plants as well as rooted vegetation. Supplementary food may be added in the form of soybean meal, fish meal, cracked corn, potatoes, or cut hay.

2.3 Commercial Practices for the Culture of *Procambarus clarkii*

The commercial culturing of *P. clarkii* in Louisiana has grown from several hundred hectares in the late 1950's to early 1960's (Gary 1974) to over 19 000 in 1977 (Fowler and de la Bretonne 1977, in Huner 1978). In 1977 the Louisiana crayfish industry was valued at $6 M by the Louisiana Department of Agriculture (Fowler and de la Bretone 1977, in Huner 1978). This estimate was considered to be conservative.

Since commercial crayfish culturing in North America is almost exclusively practised in South Louisiana (Nolfi 1980), management techniques employed in this area are described.

Gary (1974) grouped Louisiana crayfish ponds into three types: open, swamp and rice field. The open pond is treeless while the swamp has trees. The swamp and open ponds are generally located on natural-levee back lands of bayous and rivers, while the rice field is found on the rice producing prairies.

Open ponds are the most common and productive of all pond types. They are categorized as small, medium and large (Gary, 1974). Small ponds may be up to 13.9 ha and are generally family-type operations. Medium sized open ponds range from 14.0 to 39.9 ha and are generally owned and managed by a family with one or two commercial fishermen helping with harvest. Large ponds at least 40 ha in size are usually owned and managed cooperatively and are harvested by commercial fishermen.

The average per hectare crayfish production in swamp ponds is apparently 225 kg lower than the 575 kg/ha estimated for open or rice field ponds. The per hectare yield of swamp ponds is the lowest because of the lack of good forage vegetation, low oxygen

and low water temperatures. The average size of the swamp pond is 190 ha. Some clearing is necessary for access during harvesting if the trees in the swamp are closely spaced.

The rice field ponds used for crayfish culturing in Louisiana average 100 ha in size. Approximately half of the rice field ponds are approximately 40 ha in size. This is a popular size since two or three secondary interior levees running the length and/or the width of the pond are required for water-depth control. These structures are desirable in that they provide convenient access to the pond for harvesting. The crayfish are raised in rice fields in rotation with rice. Although crayfish may feed on young rice shoots, damage is minimal because the crayfish live in burrows when the shoots are young. Since the rice cultivation requires levees that can hold about 15 cm of water, rice straw must be returned to the field to provide protective cover for crayfish against predation by birds which poses a serious problem at this depth.

Management practices of the Louisiana crayfish ponds were described by Huner and Avault (1976). New ponds are stocked with ovigerous females in the spring. They are then drained and left dry for the summer. Draining induces burrowing and reproduction, eliminates predaceous fish and allows the growth of annual grasses that serve as a food source when the ponds are flooded in the fall. The first two weeks in October are the recommended period for flooding. Harvesting takes place from January through May when the pond is drained again. The crayfish populations of the ponds are expected to be self-perpetuating and therefore restocking should not be necessary.

Reproduction in the ponds is continuous from September through June with several major waves of recruitment of young-of-the-year in the fall and winter (Avault et al 1974; Huner and Avault 1976). Marketable crayfish are generally longer than 10 cm (Avault et al, 1974). They can grow to marketable size in three months (Huner and Avault 1976) following reflooding of the ponds. Louisiana ponds consistently produce 500 to 1000 kg of crayfish per ha per growing season (Avault et al 1974).

In the middle Mississippi Valley, crayfish are harvested incidentally to regular fish culture operations. Whereas the crayfish cultured in Louisiana are sold mainly for food, these crayfish are sold for fish bait.

2.4 Evaluation of Crayfish Aquaculture

The crayfish that has been selected as the most suitable for commercial culture as a food item is *P. clarkii*. Huner and Avault (1976) have found that the main difference between

various areas in the culturing of this species is the length of the growing season. In the southern United States its growing season covers the fall-winter-spring period while in the extreme North its growing season covers the summer period. According to Huner (1978) temperature appears to exert a strong control over the growth of *P. clarkii*. Thus by adding heat to the culture system it should be possible to extend its growing period at northern latitudes.

It is not known whether draining of the ponds is essential for the crayfish to complete their life cycle or whether it is practiced in Louisiana mainly to discourage the establishment of predators entering the ponds through natural water systems. In a thermal aquaculture system water is recirculated and predator species are not a problem. Thus in such a system it may be possible to have a continuous culture rather than a seasonal one if the dry period is not a necessary part of the life cycle of the crayfish.

Since the market for crayfish as a human food item is quite limited in Ontario at present, marketing schemes for this crustacean will be necessary. Griffin (1975, in Nolfi 1980) suggested relatively high prices and very low-key advertising which would be consistent with the concept of crayfish as a gourmet item to be sold at better restaurants and specialty food stores. The prices set for the crayfish should offset the price of heating the culture system. The palatability of crayfish should facilitate the development of a market. Crayfish have been described as having a "great" taste which is a cross between a lobster and shrimp, and more delicate and sweeter than other kinds of seafood (Toronto Star June 1, 1983).

P. clarkii is amenable to culturing and has a potential market. In addition techniques for the commercial culturing of this crayfish are technically viable. This species should be considered for development in thermal aquaculture. It is necessary to conduct research on the effect of temperature on the growth rate of *P. clarkii* and to develop a technically viable thermal aquaculture system before a pilot study can be undertaken.

3.0 *Macrobrachium rosenbergii*

The giant Malaysian prawn, *Macrobrachium rosenbergii*, is widely distributed in the Indo-Pacific region, including large areas of Southeast Asia, India, Australia and the areas around the South China Sea (Sandifer and Smith 1978; Malecha 1980). Adults are usually found in freshwater. During the breeding season females

carrying eggs move from freshwater to more saline water in the lower reaches of estuaries where the eggs are hatched (Sandifer and Smith 1978). The adult females then return to freshwater while the larvae are swept further downstream into more saline waters where they go through 11 larval stages within three to seven weeks. The young prawns move to freshwater following metamorphosis from the larval to the juvenile state.

M. rosenbergii is considered an attractive species for aquaculture because it will mature, mate and spawn readily in captivity throughout the year (Sandifer and Smith 1978). It is also hardy, omnivorous, and grows rapidly to a large size. Since postlarval development to adulthood is accomplished in freshwater, facilities for raising juveniles (growout facilities) can be located inland rather than in expensive coastal areas. Also, prawns are a luxury product with high market value.

The species may spawn as many as four times a year in captivity (Corbin et al no date). Females carry 20 000 to 80 000 eggs on their tail which hatch out in about 20 days (Brick and Davis, 1981). In Hawaii the typical harvest from a 40 - 50 g female is 20 000 larvae. The larvae reach the postlarval stage in about 35 days. Prawns of average market weight (45.6 g) can be harvested seven to nine months followng stocking of postlarvae into growout ponds (Malecha 1980). In Hawaii the wholesale price in 1980 was approximately $4.00 US/lb ($10.00/kg) and the retail price between $6.50 and $7.00 (Malecha 1980).

3.1 Culturing of *Macrobrachium rosenbergii*

The most successful commercial culturing of *M. rosenbergii* is being conducted in Hawaii. Shang and Fujimura (1977, in Malecha 1980) have identified the economic viability of prawn culture in Hawaii. In 1972, the industry consisted of 0.6 ha with an annual production of 1944 kg. It grew to approximately 340 ha by 1979 with an annual production of 120 000/kg valued in excess of $1 M (Malecha 1980).

M. rosenbergii was first cultured to the juvenile stage in tanks in Malaysia for the purpose of stocking rivers and was first cultured to adults of marketable size in Hawaii (Segal and Roe 1975). The species has been imported into Hawaii, Tahiti, North, Central and South America, the Caribbean, the United Kingdom, Japan and Taiwan for aquaculture studies (Sandifer and Smith 1978). Since 1977 commercial farming of freshwater prawn has been practised in Florida, Texas, California, Puerto Rico (Hanson and Goodwin 1977, in Kneale and Wang 1979) and Jamaica (pers com D.W. Stechey). *Macrobrachium rosenbergii* presently

cultured commercially is the Anuenue strain which originally came from a stock from Penang, Malaysia, and has proven to be sufficient for profitable production (Malecha 1977). However, prawn culturing need not be restricted to this strain. *M. rosenbergii* has a wide geographical distribution covering a wide variety of environmental conditions and its various populations represent a diverse genetic resource for domestication (Malecha 1980).

The mass rearing techniques used by the industry in Hawaii were developed by Fujimura and Okamoto (1970, in Malecha 1980). Malecha's (1980) description of the culture techniques is summarized in the following paragraphs.

Prawns mate in commercial ponds and females brood their eggs in 300 gallon tanks containing brackish water. The newly hatched larvae are then transferred to larval rearing tanks containing brackish water (salinity of 16 parts per thousand). The tanks are initially stocked at a rate of 130 larvae/L. This is split into 43 larvae/L over the three-week larval development period. On the average between 15 and 20 larvae/L are produced. The newly hatched larvae are fed *Artemia nauplii* (Brine shrimp larvae) and strained fish flesh. The prawn larvae are reared in water containing about 5×10^5 to 1×10^6 cells per mL of the unicellular phytoplankton *Chlorella*. The "greenwater" is cultured in 18 950 L circular tanks and pumped into rearing tanks which are flushed every two days after the first 12 days. The "greenwater" acts as a biological filter increasing survival by maintaining good water quality through waste removal.

The pond management strategy used in Hawaii consists of regularly stocking earthen ponds with hatchery-reared juveniles and regularly harvesting marketable sized prawns. Shortly following metamorphosis, postlarvae are stocked at a rate of 16.1 animals per square metre of pond bottom.

The ponds range in size from 0.25 to 4.0 acres (0.1 - 1.6 ha) and range in shape from square to rectangular with a length-to-width ratio exceeding 3 to 1. Embankment slopes vary from 1.5:1 to 2.5:1 depending on the soil type. Additonal land is required around the ponds for 15 foot wide berms and access roads.

Grass is planted on the road banks to stabilize the banks and provide shelter for young and molting individuals. The grass is also a supplementary food source for the prawns.

The ponds are supplied with water from wells or streams. Water flows into the ponds at a rate of 15 to 25 gal/min/acre (142 to 238 L/min/ha) and is discharged at 5 to 15 gal/min/acre (48 to

143 L/min/ha), taking into consideration evaporation and seepage. Phytoplankton help maintain good water quality and contribute to the food chain in the pond.

The prawns are fed chicken broiler starter in the evening by broadcasting from the banks. The average conversion ratio is 3.3:1. Seven to nine months after the initial stocking, harvesting of animals greater than 5 in (12.5 cm) long begins. The "Continuous Harvest System" involves periodic culling of market sized animals, leaving the rest of the undersized animals to grow and replace the culled individuals. Harvesting is conducted constantly year round with a slight decrease in yield obtained in the winter months. The average yield currently is 3 000/lb/acre/yr (3322 kg/ha/yr).

The continuous harvest system used in Hawaii produces higher yields and larger, more uniform sized prawns than the single harvest system used in Asian Countries. In the single harvest system the ponds are drained and all prawns, regardless of size, are harvested at the same time. Typical yields are about 1,000 lbs/acre/yr (1107 kg/ha/yr).

A difficulty encountered in many areas where fresh water prawn farming has been attempted is the short growing season caused by the low winter temperatures (Kneale and Wang 1979). Farmanfarmaian and Moore (1978) identified the optimal temperature for the growth of *M. rosenbergii* to be in the range of 29 to 31°C. Between 20 and 30°C its growth rate doubled with every 5°C temperature increase. At 35°C growth and survival was generally poor.

Temperatures below 23°C are lethal for young juveniles (Kneale and Wang 1979). A six-month growing season has been reported for South Carolina (Sandifer and Smith 1978, in Kneale and Wang 1979) and a nine-month season has been suggested for central Florida (Willis and Berrigan 1977).

The possibility of extending the growing season of *M. rosenbergii* by adding heat to the culture system is being investigated at the University of Nevada, Reno. A project using power plant effluent and/or geothermal water has been underway since 1976. In a pilot study a one acre pond stocked in April of 1979 produced a harvest of 1000 lbs (1107 kg/ha) of prawns between mid-September, 1979, and mid-January, 1981.

Techniques for the intensive culturing of *M. rosenbergii* using tanks for both the nursery and growout phases are still in the developmental stage.

In tank-reared cultures the species' aggressive behaviour and cannibalism on molting individuals in high density situations pose major problems. Peebles (1980) found that in ponds the prawns segregate by molt state into different microhabitats which increased the chance of survival of the susceptible animals.

To minimize mortality caused by aggressive and cannibalistic behaviour, Smith and Sandifer (1975) have suggested the use of tanks with large surface areas or with shelters. Such tanks reduce the frequency of aggressive interactions and make more efficient use of the water column. In their experiments animals reared in tanks containing artificial substrates in the horizontal configuration grew faster and had a higher survival than those reared in tanks without the substrates. The horizontal substrate units, 48 x 20 x 18 cm high, had plexiglass frames covered with 0.5 m of fiberglass screening.

Mancebo (1978) used horizontal substrate units in rearing tanks and was able to obtain information on the growth and survival of *M. rosenbergii* under intensive culture conditions, a requirement for commercial rearing. He used 3028 and 18 927 L capacity tanks. The smaller tank was maintained at 29°C and the larger tank at 26 - 31°C. The tanks were stocked at densities of 33 to 115 prawns/m^2. After 60 days the animals were counted and weighed. The populations were then reduced to 22 or 33 prawns/m^2 by removing the smallest animals. This procedure was repeated following another 60 day incubation period. Restocking in this phase was at 14 prawns/m^2. Following a final 60 day growout period the average weight of the animals in the smaller tank was 21.4 g and in the larger tank was 17.0 g. Survival in the tanks was approximately 80% during the first and second 2-month culture periods and approximately 70% in the third growout period. Mancebo's (1978) study indicates that with selective culling, tank-reared populations of *M. rosenbergii* can reach a mean weight of 18 g in 6 months, a considerably lower weight than is attained in pond systems.

3.2 Evaluation of Freshwater Prawn Aquaculture

The review indicates that *M. rosenbergii* is culturable and that this species is an attractive species for aquaculture because of rapid growth, high spawning frequency, high yields, and high market value.

Investigations into the effect of temperature on the prawns have indicated that growth is dependent on the length of the growing season or on the length of time that optimum temperatures prevail. The optimum temperature range in this case is substantially higher than ambient water temperatures in southern

Ontario. However, the addition of heat to the culture systems adapted to local conditions may allow this species to be cultured in the temperate zone. The cost of providing brackish water in the hatchery and nursery phases or alternately the cost of purchasing postlarvae in addition to the cost of heating the culture system should be recovered by the high market value of these crustaceans.

M. rosenbergii is culturable, and technically viable commercial culturing techniques have been developed. It also has a ready market and can fetch a premium price. This species should be considered for further development in thermal aquaculture. As in the case of *P. clarkii* the effect of temperature on the growth rate of *M. rosenbergii* should be investigated and thermal aquaculture systems and culture techniques should be developed before a pilot project can be initiated.

4.0 *Homarus americanus*

The lobster, *Homarus americanus*, is a nocturnal marine animal whose natural habitat extends to 150 fathoms or more in the Atlantic Ocean (Clark and Conklin 1981). The behaviour of *H. americanus* has been described as solitary and aggressive (Herrick 1911, in Van Olst et al 1975), characteristics not conducive to high density rearing. Juvenile lobsters have often been found in tunnels and crevices excavated in mud bottom areas (McIntosh 1920, in Van Olst et al 1975).

In nature egg development requires about two years (Aiken and Waddy 1976). The lobsters grow relatively slowly requiring five to seven years to reach market size (carapace length 8.1 cm). Cooper (1977, in Bartley et al 1980) reported that wild lobsters grow to 454 g in four to ten years at ambient temperatures of 8 to 15°C.

The growth of the lobsters can be readily increased by the manipulation of environmental factors (Bordner and Conklin 1981). Lobsters reared at 22°C can attain the size that wild lobsters reach in four to ten years in as little as 8 to 24 months (Hughes et al 1972, in Bartley et al 1980). Bordner and Conklin (1981) found that optimum growth could be obtained by providing a constant supply of food (daily feeding) and by decreasing photoperiod to near constant darkness (LD 1:23). In addition to manipulating environmental factors, the ablation of the eyestalk, which in the crustaceans has the function of regulating growth, greatly accelerates molting and increases the weight gain of the molted lobster.

With the possibility of increasing growth rates of lobsters grown in culture and the commercial production of fresh lobsters for marketing year round, the development of methods for the commercial culture of *H. americanus* has gained interest.

Lobsters are aggressive with agonistic encounters in communal tanks found to occur during establishment of dominance heirarchies (Aiken and Young-Lai 1979). They are also cannibalistic during time of molt. These behavioural characteristics are major obstacles in the development of mass culturing techniques.

4.1 Culture Methods for Lobsters

Commercial production of lobsters in culture systems has not yet been attempted. Information obtained from research on the culturing of *H. americanus* has been encouraging and the species has been designated as having high priority for commercial culture (Van Olst et al 1980).

Culture requirements and techniques for the commercial rearing of lobsters have been summarized and reviewed by Van Olst et al (1980). Their description of culture techniques as well as their recommendations are presented in the following paragraphs.

On the basis of what is known about the biology of lobsters, Van Olst et al (1980) recommend a three phase process for the commercial farming of *H. americanus*. The first phase involves the culturing of larvae, the second phase the communal rearing of juveniles and the third phase the rearing of lobsters to market size in individual compartments. Individual rearing containers are necessary in the third phase to eliminate losses due to cannibalism. All three phases require seawater.

Culture systems for the larvae should provide good water circulation to ensure that the larvae and their food remain in suspension and are evenly distributed. If the larvae are not separated and are allowed to merge, high mortalities will result from cannibalism and fouling. The culture system should have a filtration system, capable of maintaining high quality water and operate as a fully closed recirculating system, require only routine surveillance, incorporate a temperature control, and have provisions for disease control.

In a typical hatchery operation, egg-bearing females are held in tanks either individually or communally if the claws are banded. The larvae are removed from the brood tank as soon as they are free-swimming and placed in the planktonkreisel culturing units which provide proper water circulation while keeping

the larvae separated thus preventing cannibalism. The newly hatched larvae can be fed live adult brine shrimp, and other foods including frozen foods and artificial preparations. The larvae can be fed either generously late at night and then not again until morning or at regular intervals during the night by an automatic feeder.

Following molting to stage IV the lobsters can be transferred to a system designed for juvenile culture. The juveniles may be reared in communal tanks even though relatively high losses due to cannibalism can be expected. At this stage of growth the losses may be tolerable in terms of labor and food costs. However at one point the losses can no longer be tolerated economically and the animals must be separated to avoid further loss to cannibalism.

The methods that have been investigated for rearing of lobsters have taken into account the need for separate compartments for each animal, a constant supply of oxygenated seawater to each animal, a method for feeding and removal of waste matter, as well as an environment that allows for rapid uniform growth and high survival. An additional requirement is adequate space. Growth and survival of lobsters have been found to be reduced when they are reared in small containers (Van Olst and Carlberg 1978). For unrestricted growth an area approximately three times the total body length of the lobster (approximately 1 m^2/454 g lobster) is required.

Van Olst et al (1980) point out that almost all the culture systems proposed for rearing *H. americanus* are capital intensive. They conclude that commercial production of lobsters will be a complex operation requiring expensive specialized equipment and techniques. Areas identified as still requiring research are the refinement of artifical diets, the reduction of diseases associated with nutritional deficiency, the development of methods for routine production of larvae, the reduction of cannibalism, and the improvement of designs for individual rearing.

4.2 Evaluation of Lobster Aquaculture

The growth rate of lobsters can be increased by maintaining them at temperatures above their natural ambient temperature range and in this respect they are ideal for thermal aquaculture. However the culturability of lobsters has not as yet been demonstrated and the culture systems that have been designed to date are technically demanding and capital intensive. In addition, lobsters require salt water rather than freshwater rendering

inland culturing of this crustacean impractical. Therefore further development of *H. americanus* for thermal aquaculture is not recommended.

5.0 RECOMMENDATIONS AND CONCLUSIONS

The technical and economic viability of *Procambarus clarkii* and *Macrobrachium rosenbergii* aquaculture has been proven in warmer climates. Culturing of these two crustaceans may be possible in southern Ontario if heat is added to culturing systems adapted to local conditions. In the case of lobsters mass culturing techniques are still under investigation and have not been proven as workable.

Based on their culturability and the advanced state of development in the culture techniques of *P. clarkii* and *M. rosenbergii* further development of thermal aquaculture of these two species is recommended.

Research on the effect of temperature on the growth rates of these species and appropriate techniques will be necessary and thermal aquaculture systems which will provide the required temperatures will have to be developed. The cooperation of engineering groups will be needed for the development of an energy efficient water heating unit for the culture systems. Waste heat discharges from generating stations are a potential supplementary source of heat.

A comparison of culturing aspects of *P. clarkii* and *M. rosenbergii* indicates that although both grow rapidly to a large size the culturing of *M. rosenbergii* will be more capital intensive than the culturing of *P. clarkii* due to their requirement for brackish water hatcheries and nurseries or alternately the need for purchasing postlarvae. The prawns also require higher temperatures than the crayfish which makes the culturing of the prawns more expensive than the culturing of the crayfish. However the average commercial yield of *M. rosenbergii* in Hawaii is about three times the average yield of *P. clarkii* in Louisiana. In addition the prawns have a higher proportion of edible tissue than *P. clarkii* (approximately 9% versus 50% of the total weight, pers com D.W. Stechey) just as shrimp have relative to lobster. Further the prawns have a ready market demand and can replace prawns and shrimp presently imported at premium prices while marketing schemes will be necessary to create a demand for crayfish as a food item. The higher yields, market demand and premium price of the prawns should offset their higher capital investment, and renders the thermal aquaculture of prawns more likely to attain commercial viability than that of crayfish. It is therefore recommended that a more intensive effort be given to the development of thermal aquaculture of *M. rosenbergii* than of *P. clarkii*.

6.0 SUMMARY

1. Of the crayfish considered for aquaculture, *Procambarus clarkii* appears to be the most desirable species for culturing as a food item on the basis of its relatively large size. It is presently commercially cultured almost exclusively in southern Louisiana.

2. *P. clarkii* ponds are stocked with egg bearing females in the spring. The ponds are drained, left dry for the summer, and flooded in the fall. Harvesting occurs from January through May when the ponds are drained again. The crayfish can grow to the minimum marketable size of 10 cm within three months of reflooding of the ponds. Crayfish culture ponds in Louisiana produce 500 to 1000 kg of crayfish per ha per growing season.

3. *P. clarkii* is amenable to culturing. Commercial culturing techniques for this species have been established. Although there is a potential market for this crustacean in southern Ontario, marketing schemes will have to be used to create a demand.

4. The giant Malaysian prawn, *Macrobrachium rosenbergii*, is an attractive species for aquaculture because it will mature, mate and spawn readily in captivity throughout the year. It is also hardy, omnivorous and grows rapidly to a large size.

5. The most successful commercial culturing of *M. rosenbergii* is presently practiced in Hawaii where egg hatching and larval prawn rearing are accomplished in tanks filled with brackish water. Postlarvae are raised in earthen ponds ranging in size from 0.25 to 4.0 ha. Harvesting of animals greater than 12.5 cm is initiated seven to nine months following the stocking of the ponds. The yield from Hawaiian ponds averages 3322 kg per ha per year.

6. *M. rosenbergii* is amenable to culturing in pond systems and commercial culturing techniques have been proven to be technically viable. In addition this crustacean also has a high market value.

7. The aggressive and cannibalistic behaviour of lobsters poses a major difficulty in the mass culturing of this crustacean. Culturing techniques that have been developed are complex, capital intensive operations, that have not as yet reached the pilot study stage.

8. The growth rate of lobsters can be increased by maintaining them at temperatures above their natural ambient temperature range. In this respect they are ideal for thermal aquaculture. However the culturability of lobsters has not as yet been demonstrated.

9. Culturing of *P. clarkii* and *M. rosenbergii* may be a possibility in southern Ontario if heat is added to culture systems adapted to local conditions. Potential sources of heat are electric heating or discharges from generating stations.

10. Based on their culturability and the technical viability of culture systems developed for *P. clarkii* and *M. rosenbergii* it is recommended that these two species be considered for further development in thermal aquaculture. Because of the prawns' high market value, high yield and high proportion of edible tissue as compared to the crayfish a more intensive effort should be given to the prawns.

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